The Scientific Inspection Method for a PSC Box Bridge Using a Remote-Control Tarantula Robot

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The needs for the automation of bridge inspections have been gradually voiced by several inspectors and researchers for more systematic and efficient maintenance. In this paper, a new inspection automation system has been introduced and tested with real PSC box crack inspection procedures along with the development of more advanced robotic and digital image processing technologies. The configuration and scheme of robotic inspection and digital image processing algorithms are also presented. This inspection system can be specified to three parts. 1) The remote-controlled tarantula robot, 2) The digital image processing program, and 3) The database system. All results are stored on the main computer of the inspection robot and are used in order to check the changes in surface cracks and any other damage to the propagations periodically. The designed robotic sensors and image processing system are tested, and the feasibility of the robot-based automatic inspection is investigated for approval of its field application to real PSC box bridges.

1. INTRODUCTION

At present, the maintenance of PSC box bridges has been performed by several inspectors as using a manual process. The inspector must work inside the PCS box and take pictures of cracks one by one. However, the manual inspection works are routine and inefficient due to the dark, narrow and harsh environment inside the PSC box structure. Accordingly, the needs for the automation of bridge inspections have been gradually voiced by several inspectors and researchers for more systematic and efficient maintenance. A new inspection automation system is introduced and tested with real PSC box crack inspection procedures along with the development of more advanced robotic and digital image processing technologies. Figure 1 shows one type of the PSC box and an inspection robot.

Fig.1 A PSC box and an inspection robot

The configuration and scheme of the robotic inspection and digital image processing algorithms are also presented. The remote-controlled robot is designed for bridge structure inspection and has digital image processing functions, and a convenient user interface. A quad-tracked type unmanned robot is designed and tested for the measurement and processing of internal cracking in this research, and the feasibility of its field implementation is tested in a real inspection environment. The inspection system can be divided into three parts. 1) The remote-controlled tarantula robot system, 2) The digital image processing program, and 3) The database system. Unmanned and automated inspection can be performed with these three components. This robotic and digitalized inspection procedure is able to substitute the routine and hard manual PSC box bridge inspection and maintenance works.

2. COMPOSITION OF THE INSPECTION SYSTEM

2.1 The remote controlled tarantula robot

Remote-operated robot technology was introduced for the PSC box inspection. The robot can be controlled by a remote operator, located on the outside or entry point of PSC box. It has an image gathering system such as a high resolution digital camera, an image processing module and a localization sensor system. The localization sensor shows the specific and unique position of the robot and the captured images of the PSC box. The quad-track type tarantula robot was designed for this research in order to overcome the structural barriers between the boxes.

2.2 The digital image processing and database system

The image processing system has three functions ‘image input/output’, ‘defect management’ and ‘defect detection’. This image processing system can detect the main cracks inside the surface of the PSC box bridge by automatically processing all photographs taken by the high resolution digital cameras. The pictures are stored in a main computer and are used to check the changes in the surface crack propagations periodically.

For unmanned inspection, digitalized processing is more efficient to detect, verify and classify the status of the cracks in PSC boxes. The high precision digital camera and digital image processing computer system were used for this unmanned inspection. The digital image processing system can detect a crack from image and maintain the result in the database.

3. THE REMOTE CONTROLLED INSPECTION ROBOT

3.1 Components of the inspection robot system

Figure 2 shows the overall configurations of the inspection robotic system. It is composed of a remotely-controlled robot, a distance measuring sensor, an operation system and a post-processing software module. The sensors are mounted on the robot. It can also be divided into two parts. One is a localization sensor such as an LDM (Laser Distance Meter) and an ultrasonic ranger. The other is a digital camera for the capturing of crack images. These sensors are controlled by an embedded main controller. In addition, Figure 2 shows the digital image capturing camera, the pan/tilt equipment, the CCD/IR camera, the motor driver and the image/data transfer system. Figure 3 shows the portable remote control system for the inspection robot and the robot monitoring software was represented in Figure 4.

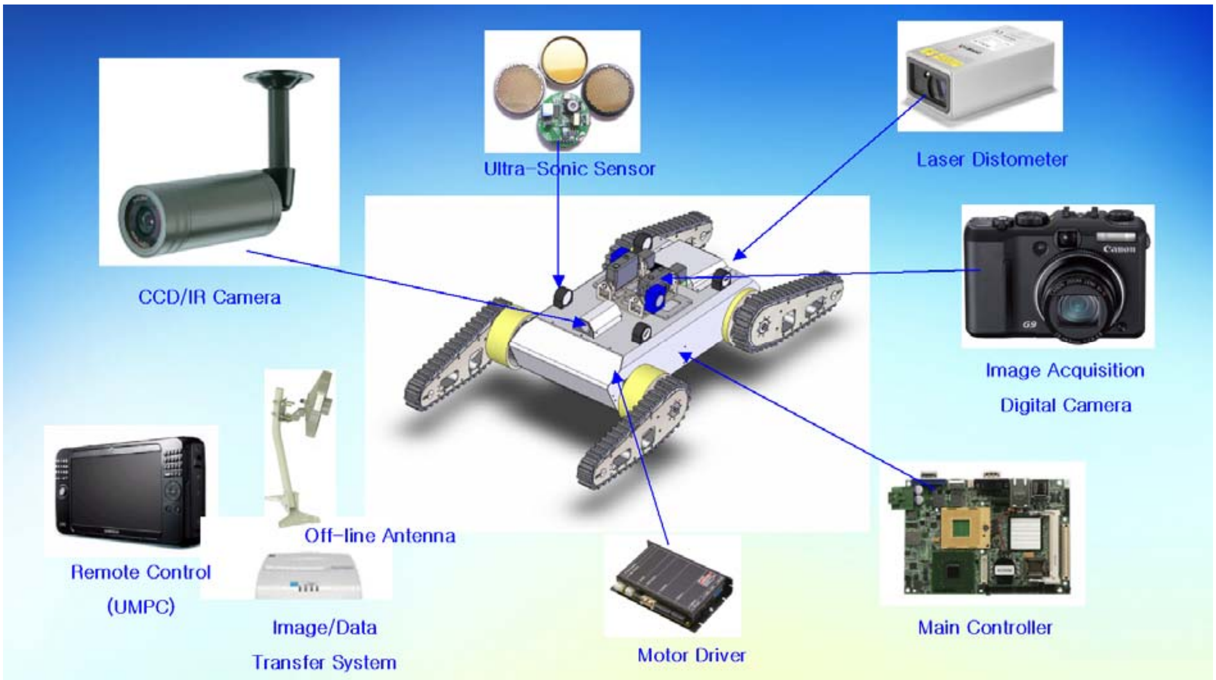


Fig.2 The overall configuration of the inspection robotic system

Fig.3 The remote-control system

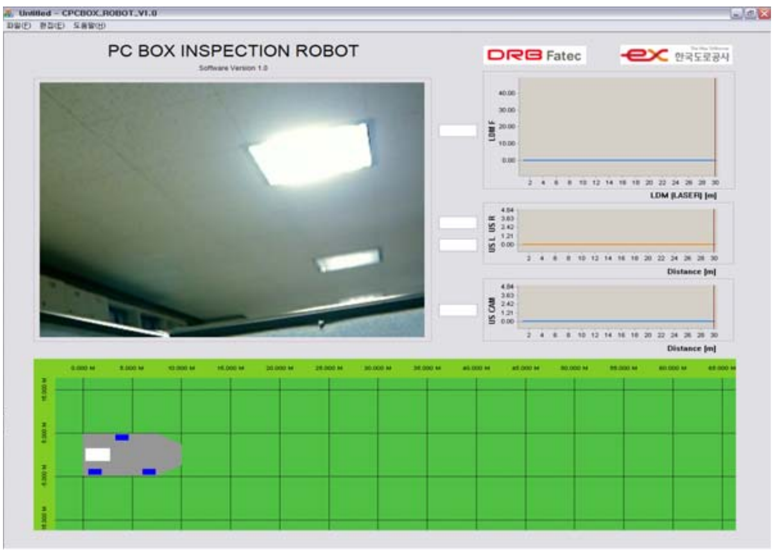


Fig.4 The inspection robot monitoring software

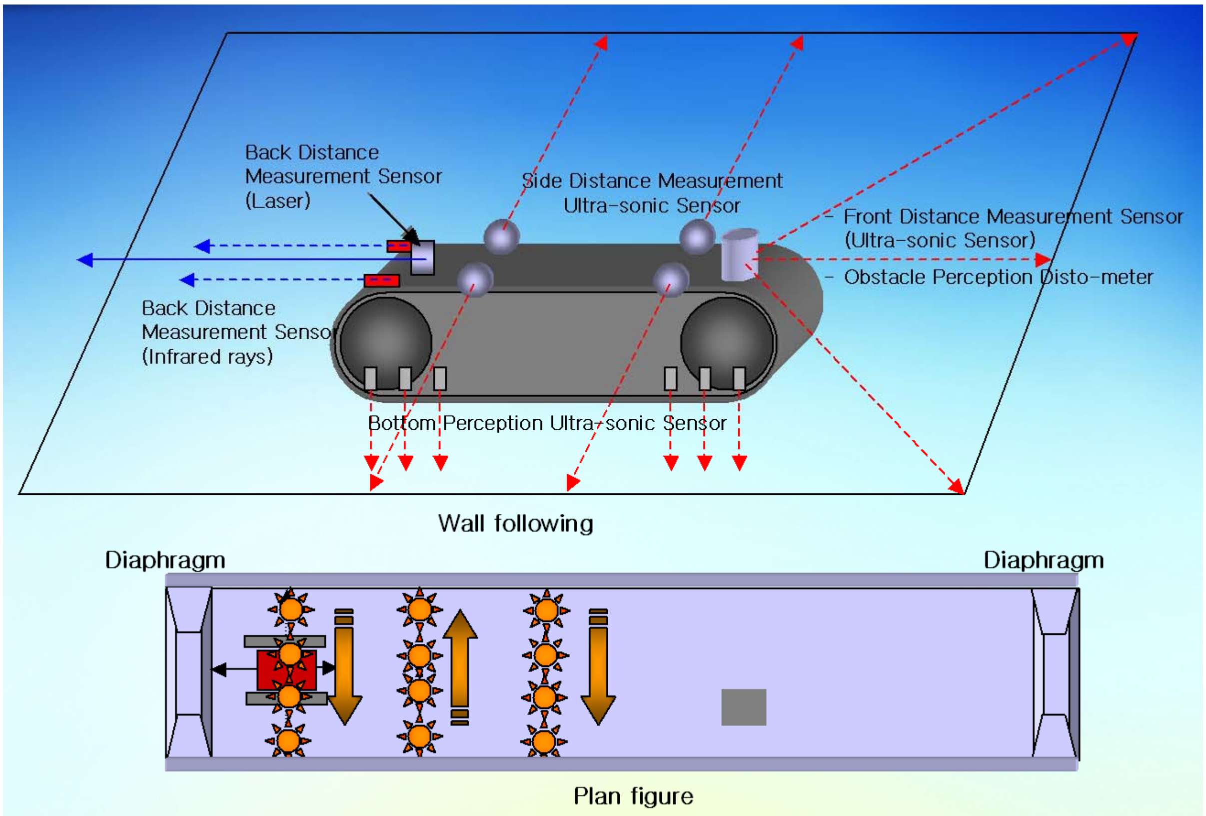


Fig.5 The localization mechanism and image acquisition

3.2 Localization inside the PSC box and the methods for acquiring images

The localization procedure is to find out the current positions of the inspection robot inside the PSC boxes. There is no index for positioning within PSC boxes. A general outdoor positioning scheme, such as GPS, cannot be used inside PSC boxes. Thus, a unique localization scheme must be devised for this process. Two ultrasonic rangers and one LDM were used for the localization. Ultrasonic rangers are used to keep the distance from the wall fixed when the robot moves. After the alignment, the LDM measures the exact distance from the starting point of the PSC box. The robot must operate the ultrasonic rangers and the LDM in order. It also counts the number of images acquired and it memorizes the ID number of the PSC box in order to calculate the global localization along the whole bridge span. Figure 5 shows the localization sensors and localization mechanism in a PSC box.

3.3 Obstacles to overcome in a PSC box

Between PSC boxes, there are trapezoidal-shaped structural obstacles. Some of these obstacles are situated more than 500mm height from the bottom of the PSC box. Accordingly, the inspection robot should overcome the obstacles and take images inside the PSC boxes. Thus, a unique and systematic maneuvering procedure was proposed and tested for the actual 500mm obstacles. A unique quad-track tarantula robot was designed for obstacle overcoming by remote control. Figure 6 shows several of the maneuvering modes for the quad-track robotic mechanism.

(a) (b) (c) (d) (e) (f)

Fig.6 The mechanism for overcoming obstacles

4. THE DIGITAL IMAGE PROCESSING SYSTEM

4.1 The image processing system

The “image input/output” part of the image processing system can read the images acquired by the bridge inspection robot and save or print the defect information detected. The “defect management” part manages the acquired images and the defect information measured from each bridge in a separate project file. The “defect detection” part involves the users selecting either manual or automatic mode to detect any defects, and it can calculate defect information such as the length and thickness of a crack, and the range and area of white coating. A crack network diagram can be generated from the detected cracks so that the current safety status of such a bridge can be easily evaluated.

4.2 Crack detection

The automatic detection of a crack takes place in the order shown in Figure 7.

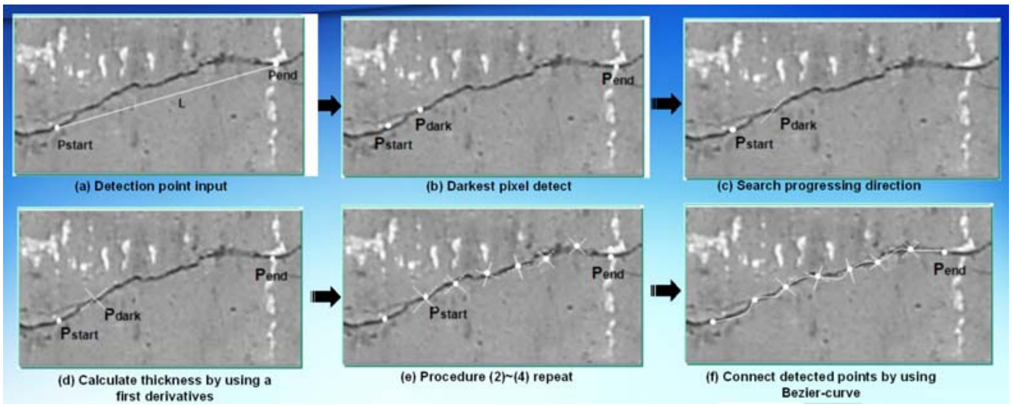


Fig.7 Automatic crack detection process

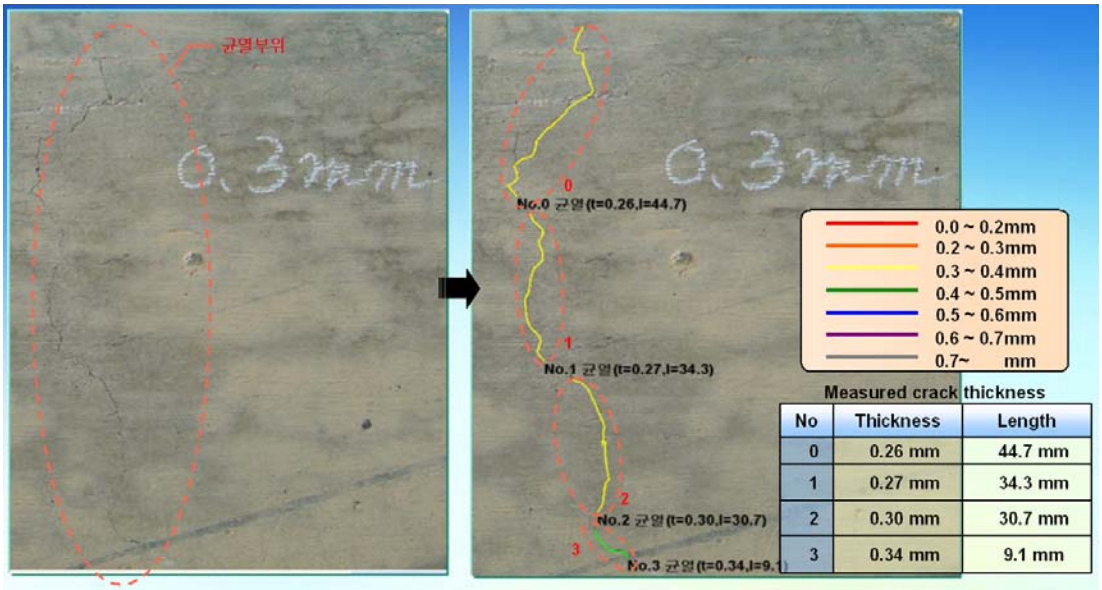
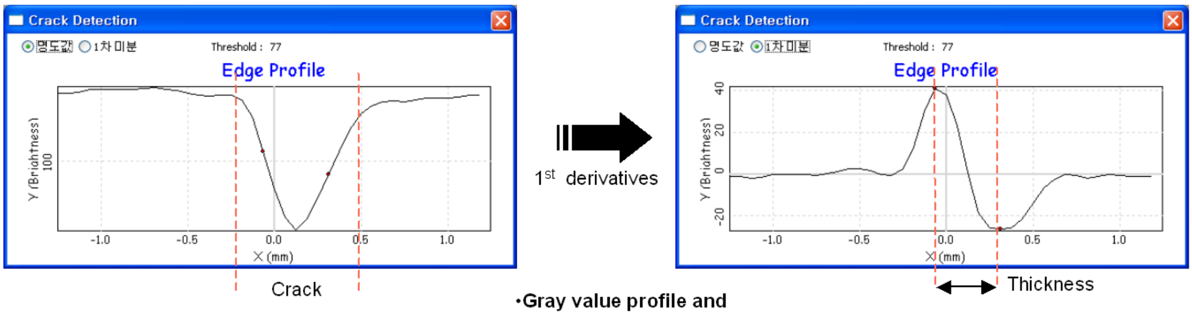


Fig.8 Measured crack width

First of all, the user enters the point at which the slope of the defect changes (inflection point). Then individual inflection points are connected with virtual straight lines and their slopes are calculated. This process enables us to determine if the direction of cracking is either horizontal or vertical, based on

the absolute value of the slope. The thickness of the crack shall be searched vertically when the virtual line is horizontal, whereas it shall be searched horizontally when the virtual line is vertical. Then, the thickness of the crack is determined by the number of overlapped pixels with the darkest color in the search direction. Detected cracks are color-coded according to their thickness, and their crack numbers, lengths and dates of detection can be marked on the side so that the crack status can be recognized instantaneously. Figure 8 and Figure 9 show that the numerically-measured crack width can be calculated by using a crack edge profile. Users can obtain crack width data more easily using this software.



•Gray value profile and

Crack detection result using a first derivatives (0.3mm crack)

Fig.9 Crack edge profile

5. THE DATABASE SYSTEM OF THE DIGITAL IMAGE

5.1 Database structure

As shown in Figure 10, the results for the inspection can be implemented in a tree structure. One unit of a bridge is equivalent to one unit of a project and one project is divided into sections, columns and rows, depending on the location of the box and the location of the robot.

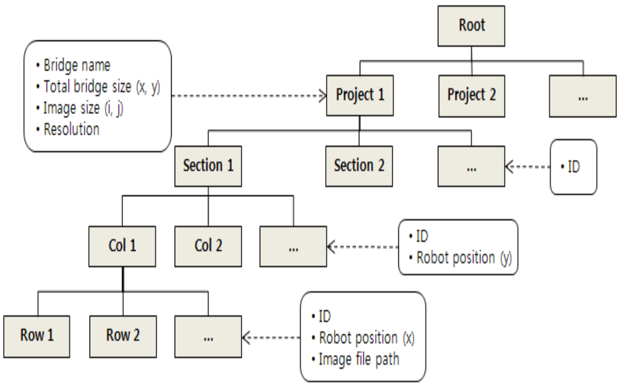


Fig.10 Database structure

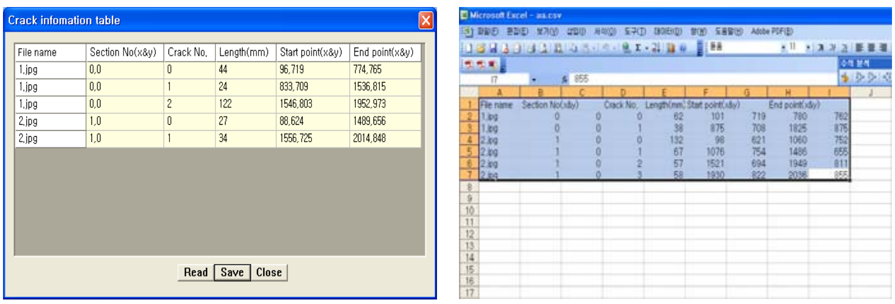


Fig.11 The crack results and database

The common data relating to the bridge's name, size and measurement accuracy is stored in the

project. The lower section, column and row have their own unique IDs and the location of the robot at the time when the image is obtained. The file directories for the saved image file are also stored in them. The project size varies depending on the entire size of the bridge and the measurement accuracy, and the measured data can be edited arbitrarily by the user. For example, a bridge measuring 15M X 50M takes up about 0.8GB of database storage capacity. However, if the use deletes everything except the problematic portion (where cracks or damages occur), the project unit will be lighter, and the storage load will be decreased significantly. As for the results, the user can manage the bridge more efficiently. Figure 11 shows that the data-based crack pictures.

5.2 Bridge Management

By using the crack network diagram and the crack tabulation, the current status of a bridge can be identified and managed. The crack network diagram can be moved, scaled up/down and printed for easy analysis of the crack status for each section of the bridge, and the crack tabulation can be exported as a document file for recording and managing the crack status of bridge. Figure 12 shows that detected overall crack map in a one PSC box image.

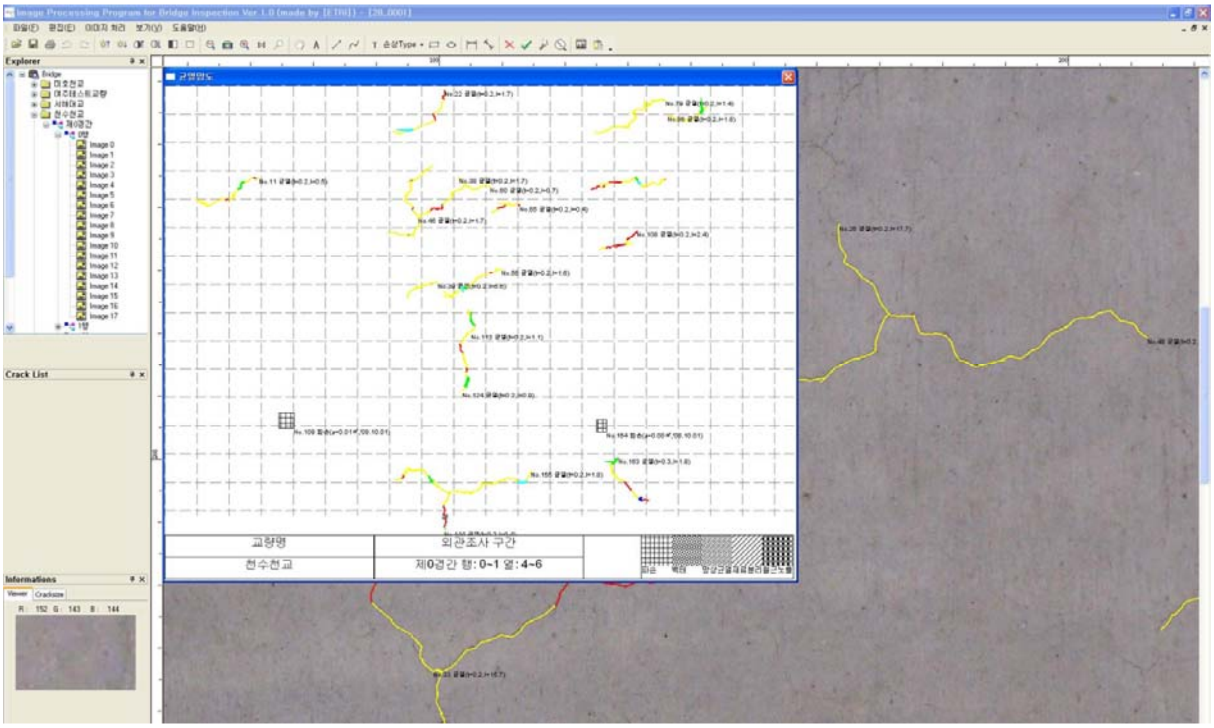


Fig.12 Crack map

6. CONCLUSION

In this paper, remote-controlled robots and digital image processing technologies were proposed as a replacement for the routine manual inspection of PSC box bridges. These new technologies were intricately designed and equipped with localization sensors and digitalized image capturing and processing devices for cracks in order to achieve the automatic maintenance of PSC boxes. The designed sensors of the robot and image processing modules were tested and the feasibility of the robot-based automation of the inspection of real PSC box bridges was verified. In addition, the automatic obstacle maneuvering sequence was designed for more efficient movement between PSC boxes. The image processing software was also upgraded to a more user-friendly environment. All users can draw out cracks with several marking tools and measure the width and length of the crack

within the image processing and database management software environment as proposed in this study.

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